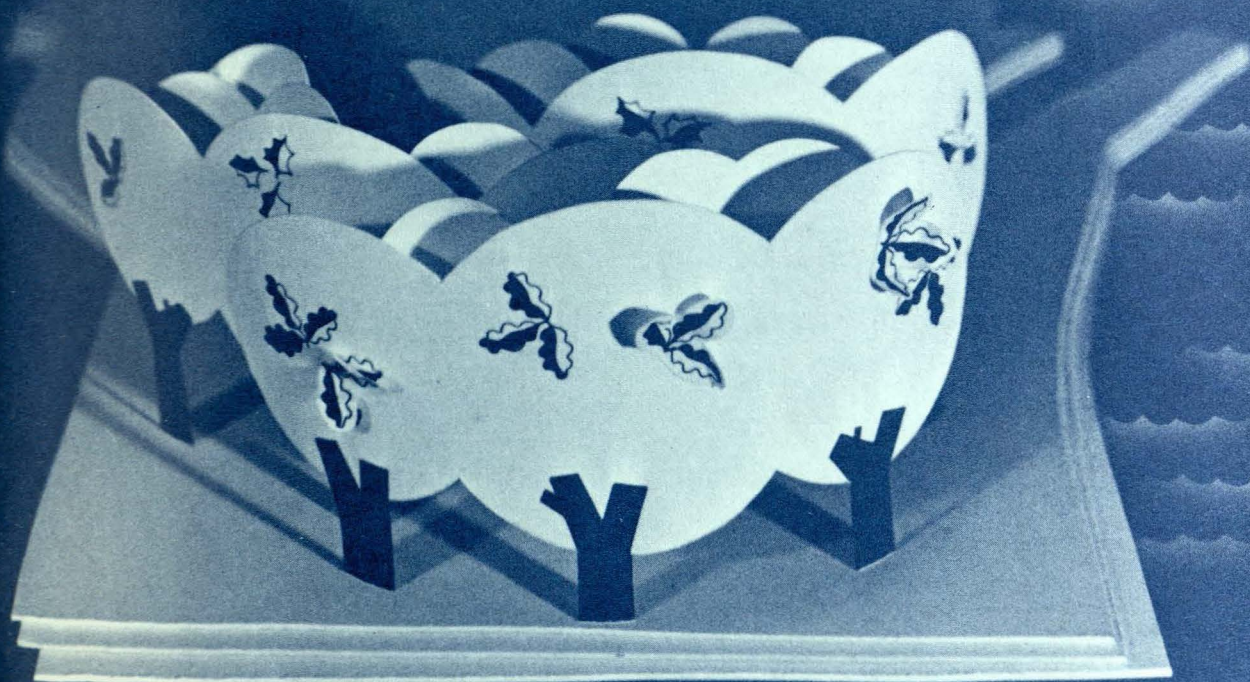


EIGHT-YEAR performance of interplanted hardwoods in southern WISCONSIN oak clearcuts BY PAUL S. JOHNSON



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EIGHT-YEAR PERFORMANCE OF INTERPLANTED HARDWOODS IN SOUTHERN WISCONSIN OAK CLEARCUTS

Paul S. Johnson

Interplanting is defined as "setting young trees among existing forest growth, planted or natural" (Ford-Robertson 1971). Thus, interplanted trees usually develop in competition with other natural woody vegetation that is continually changing because of growth and mortality. These compositional and structural changes occur relatively rapidly in hardwood clearcuts. Thus, the performance of trees interplanted in such clearcuts can be evaluated in relation to the growth of dominant competing vegetation, such as stump sprouts. To facilitate this evaluation, I used data from a study on northern red oak (*Quercus rubra* L.) stump sprout growth (Johnson 1975) to define success criterion for interplanted trees because oak stump sprouts often predominate in oak clearcuts. The present study was conducted in two 20-acre clearcuts in upland forests of Wisconsin, one on the Coulee Experimental Forest near La Crosse and the second near Albany south of Madison. On both areas, interplantings were made the spring following dormant season cutting of all trees 2 inches d.b.h. and larger. Site conditions and planting methods are detailed in Johnson (1971).

METHODS

I arbitrarily defined two criteria for judging the relative position and competitive status of interplanted trees: one assumes that trees must be at least 80 percent of the average height of red oak stump sprouts growing on a site; the second that a tree must be at least 60 percent of the height of a red oak stump sprout. The second might suffice, for example, where stump sprouting has been controlled with herbicides or where early silvicultural cleanings are planned.

To account for variation in tree height attributable to site, the minimum limits of height for these relative height criteria (RH60, RH80) were adjusted using a measure of site quality called the topographic site coefficient (Appendix I). This provided the range of site-dependent minimum heights

shown in figure 1. Using the RH80 criterion, for example, a planted tree after 8 years on the best site observed in the study areas would have to be at least 14.6 feet tall to be successful but would have to be only 12.3 feet tall on the poorest site. Using the RH60 criterion, planted trees after 8 years on the best sites would have to be at least 10.9 feet tall, but only 9.2 feet on the poorest site.

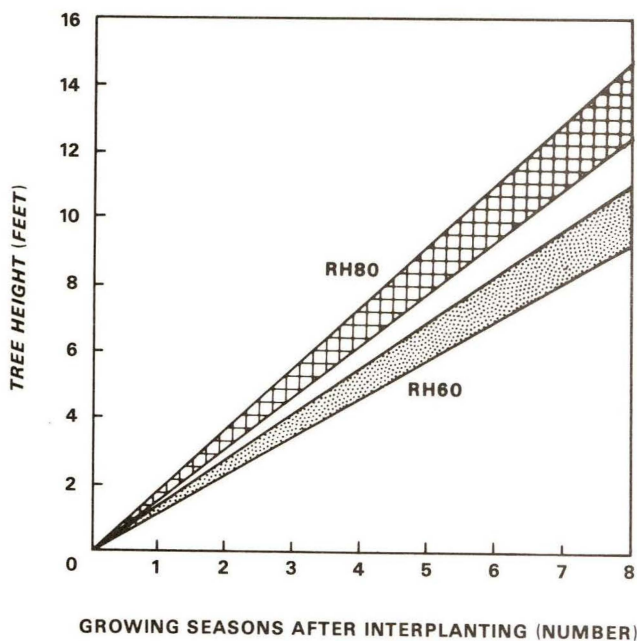


Figure 1.--Tree height in relation to number of growing seasons after interplanting for the range of minimum limits for relative heights (RH) 60 and 80. (Minimum limits for relative heights vary because of adjustments for variation in site. Thus, the lowest values (lower edge) of each relative height class are minimum tree heights on the poorest sites encountered in study plots; uppermost values (topside edge) are minimum tree heights on the best sites. Equations for height estimates are given in Appendix II.)

RESULTS

Survival, Height and Success

Among the six species planted at Albany, survival ranged from 49 percent for northern red oak to 94 percent for white ash (*Fraxinus americana* L.) (as shown in table 1). Mean height was greatest for yellow-poplar (*Liriodendron tulipifera* L.) (14.8 feet), but red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), and white ash all averaged between 12 and 13 feet. Based on the RH80 criterion, sugar maple and red maple were the most successful; white ash and yellow-poplar were only 6 to 7 percent less successful than the maples. Based on the RH60 criterion, white ash was the most successful species. American basswood (*Tilia americana* L.) and northern red oak were the least successful and also the most varied in survivor height. Although the northern red oaks had been relatively large (they averaged 20.7 inches at time of planting) only one out of four attained RH60 after 8 years.

Survival among the four species planted at Coulee was similar to that at Albany. The range was from 60 percent for northern red oak to 95 percent for white ash. Mean height was greatest for yellow-poplar, although it was nearly as tall for white ash and sugar maple. Based on the RH80 criterion, sugar maple and yellow-poplar were almost equally successful. Although the mean height of white ash at the time of planting was greatest and least variable of all trees planted, the success percentage for white ash based on attaining RH80 was only 8.9 percent. However, based on the RH60 criterion, white ash ranked second to sugar maple. Red oak showed the lowest success and greatest variation in survivor height.

Development of trees was also expressed as the probability of individual trees attaining RH60 or RH80 in relation to the number of growing seasons after interplanting. This was done by regression analysis (Appendix III). Three types of probability trends are evident in the data from the Albany plots shown in figure 2. In one type, American basswood and northern red oak decline very rapidly to a plateau of relatively low probabilities: their estimates were below 0.2 by the second or third growing season using the RH80 success criterion. For the same success criterion, probabilities for red and sugar

Table 1.--Height, survival, and success of interplanted hardwoods

Species	Height when planted				Eighth year				Planting success ¹	
	Standard deviation		Coefficient of variation		Standard deviation		Coefficient of variation		Survival	: when success criteria is relative height ²
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean		
	(In.)	(In.)	(Percent)	(Percent)	(Ft.)	(Ft.)	(Percent)	(Percent)	60	80
Northern red oak	20.7	7.1	34.5	9.4	5.3	56.0	49	25.3	49	11.6
Yellow-poplar	16.8	5.4	32.3	14.8	5.8	39.3	60	44.8	60	36.4
Sugar maple	10.9	3.6	33.2	12.1	5.9	48.8	79	52.1	79	42.5
White ash	27.2	6.2	22.8	12.4	3.8	30.8	94	70.2	94	35.5
American basswood	10.6	3.6	34.0	6.0	4.1	68.9	54	7.6	54	2.2
Red maple	10.5	4.0	37.9	12.9	5.1	39.8	80	54.5	80	42.0
COULEE SEEDLINGS										
Northern red oak	6.7	2.8	41.8	6.0	3.6	59.5	60	6.0	60	0.5
White ash	18.0	3.9	21.8	9.4	3.8	40.3	95	34.6	95	8.9
Sugar maple	6.5	2.2	33.7	9.6	4.7	49.1	88	40.2	88	14.9
Yellow-poplar	5.5	2.3	42.4	10.0	5.0	50.1	68	31.0	68	15.5

¹Planting success is the percent of planted trees surviving and reaching a given relative height after eight field growing seasons.

²Relative height is the average height (adjusted for site) of northern red oak stump sprouts at age 8 that provides the relative height standard of 100; thus a planted tree with a relative height of 80 would be 80 percent of the expected height of a red oak stump sprout growing on a similar site.

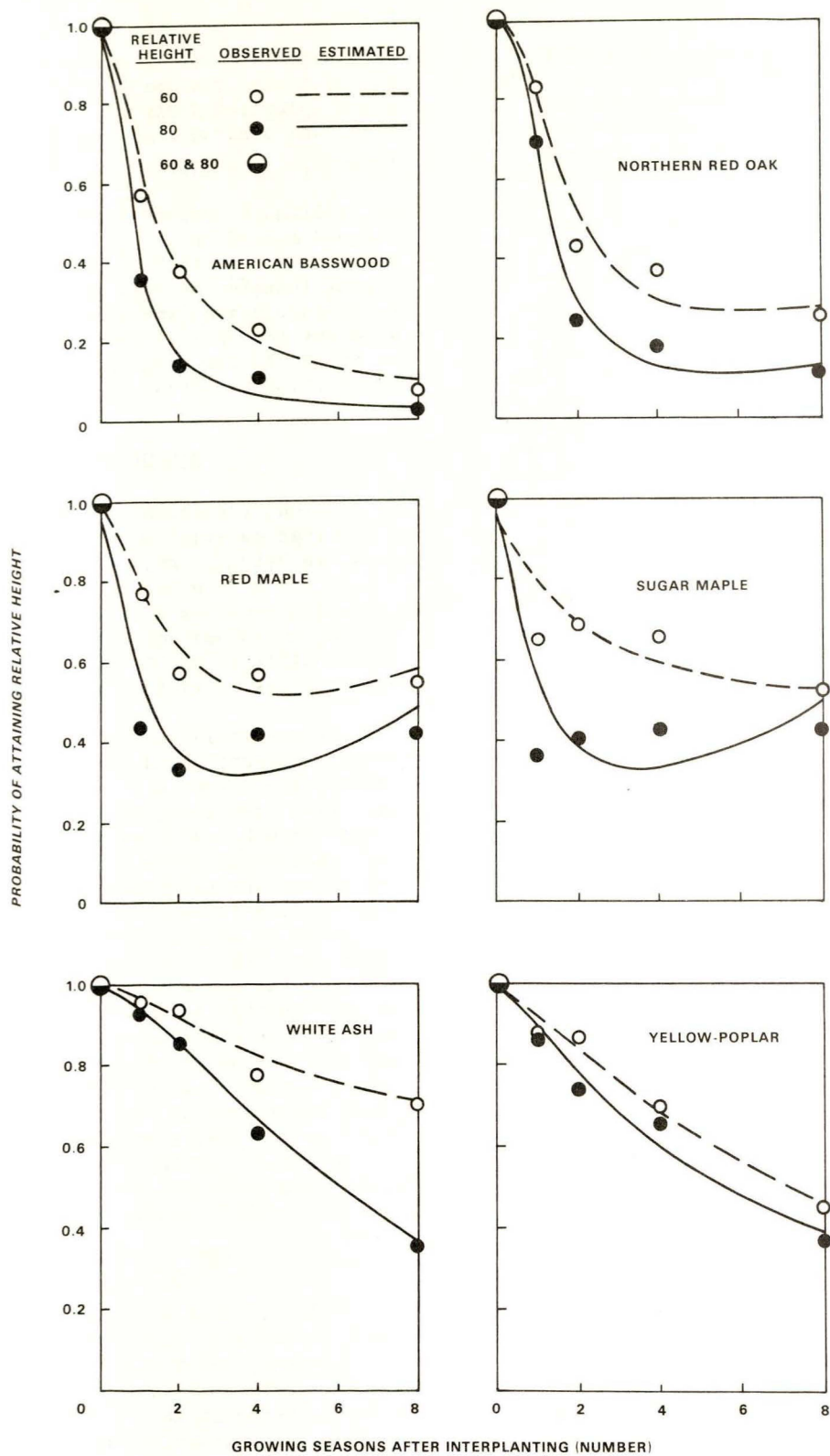


Figure 2.--Probabilities of interplanted trees attaining relative heights 60 and 80 based on 1-1 transplants interplanted at Albany. (Equations for regression estimates are given in Appendix III.)

maples also declined rapidly, dropping to near 0.3 by the fourth growing season. After four growing seasons, however, there were modest but statistically significant increases in probabilities to an eighth-year estimate approaching 0.5. White ash and yellow-poplar formed a third trend, exhibiting a relatively slow and nearly linear decline for both success criteria, and decreasing to near 0.4 for the RH80 criterion at 8 years.

All four species on the Coulee plots declined to low probabilities (<0.2) by the fourth growing season for both success criteria (fig. 3). All species exhibited some rebounding to higher values after the fifth growing season. Nevertheless, all estimates for the eighth growing season were less than 0.2 for the RH80 criterion. In contrast, based on the RH60 criterion, probabilities for all species except red oak increased to levels between 0.34 and 0.46 by the end of the eighth field growing season.

Application of Results

Even though the two study areas represent case studies, results might be applied to interplantings where quality and vegetative condition of the planting site, and size and condition of the planting stock are similar to those tested. Different seed sources, extremes in weather, and improper care and handling of stock may cause significant departures from test results. The results for yellow-poplar should be interpreted cautiously because the study areas are outside the natural range of this species.

The number of trees that must be planted to ensure at least one "successful" tree after the eighth field growing season (with probability of 0.8) is shown in table 2. Termed "planting factors," these are based on the estimated probabilities shown in figures 2 and 3; how they were derived is explained in Appendix IV.

For example, based on table 2, if a tree planter wanted to be reasonably assured of having at least 200 interplanted sugar maples per acre attain RH80 after 8 field growing seasons, he would plant 500 trees (2.5×200) per acre of the large nursery stock or 1,960 trees (9.8×200) of the small nursery stock. If he used the RH60 success criterion, only 440 of the large-size or 520 of the small-size trees would have to be planted per acre. However, if the RH60 criterion was acceptable and the

only objective was to plant a minimum number of trees, the large white ash planting stock (planting factor = 1.3) would be the best choice among the alternatives presented.

Although nursery stock is usually catalogued according to age (e.g., 1-0, 2-0, etc.), size of stock within the same age classification can vary greatly between nurseries, years, and seed sources. Thus, size (as in table 2) rather than age should be the basis for judging quality of planting stock (Limstrom 1963).

DISCUSSION

Height attainment probabilities are a combined expression of mortality and relative height growth. Growth and mortality are determined by various factors including seedling size, physiological condition, and shade tolerance, together with site quality, competition, and cultural measures used during or after interplanting.

If decreasing probabilities in figures 2 and 3 are attributable primarily to slow growth, the curves can potentially change direction with time, depending on rates of height growth. This is apparent in the red and sugar maple curves for Albany, and in the curves for all species for Coulee, where interplanted trees showed slight to moderate increases in height attainment probabilities after the fourth growing season. Where small planting stock was used, such rebounding may be attributable to a requirement for a relatively long establishment period before substantial height growth begins. Seedling shade tolerance may also be a factor. However, regardless of the cause, continued increases in height attainment probabilities are possible, and the planting factors associated with rebounding curves may be somewhat high in relation to future stocking needs.

Silvicultural cleanings and other cultural techniques can also modify growth rates and survival, which would alter success probabilities in young hardwoods. For example, moderate thinning in 7- to 9-year-old stands in Ohio significantly increased height growth of yellow-poplar and northern red oak saplings (Allen and Marquis 1970). However, it may be more practical to prevent or limit unwanted competition using herbicides immediately after clearcutting than to later thin sapling stands.

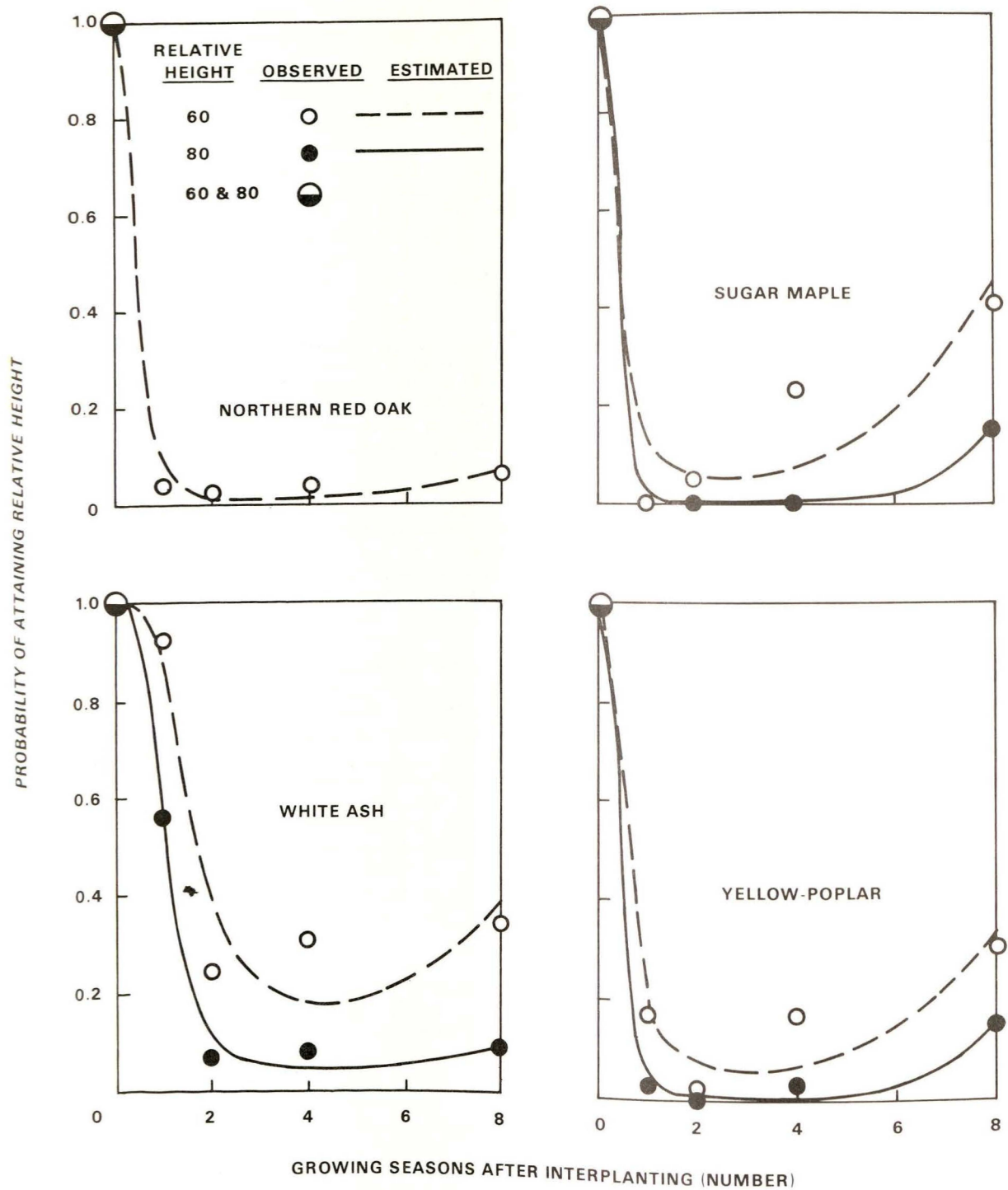


Figure 3.--Probabilities of interplanted trees attaining relative heights of 60 and 80 based on 1-0 seedlings interplanted at Coulee. (Equations for regression estimates are given in Appendix III.)

Table 2.--Planting factors¹ for two eighth-year success criteria by species and size of planting stock

Species	Top length of planting stock		Planting factor when success criteria is relative height ²	
	Mean	Range	80	60
	(In.)	(In.)		
Northern red oak	21	14-28	11.4	5.1
	7	4-10	(³)	21.3
Yellow-poplar	17	11-22	3.4	2.7
	5	3-8	9.1	3.9
Sugar maple	11	7-14	2.5	2.2
	6	4-9	9.8	2.6
White ash	27	21-33	3.5	1.3
	18	14-22	15.5	3.4
Red maple	10	6-14	2.6	1.9
American basswood	11	7-14	51.2	16.2

¹Planting factor is the number of planted trees required to produce, with a probability of 0.80 or greater, at least one "successful" tree at the end of the eighth field growing season. Assumes that shoot/root ratios of planting stock are well balanced and that stock is planted on sites similar to study areas.

²Relative height is the average height (adjusted for site) of northern red oak stump sprouts at age 8 that provides the relative height standard value of 100. Thus, a planted tree with a relative height of 80 would be 80 percent of the expected height of a red oak stump sprout growing on a similar site.

³Probability of success is too small to provide meaningful planting factor.

Herbicides should be applied before interplanting to avoid possible damage to planted trees. Where there are large numbers of small elms (*Ulmus* spp.), black cherry (*Prunus serotina* Ehrh.), boxelder (*Acer negundo* L.), and eastern hophornbeam (*Ostrya virginiana* Mill. (K. Koch)), herbicides should be applied immediately after cutting. Stumps of these species produce dense, rapidly growing sprout clumps that can overtop interplantings during the first 20 years of stand development. Where there is potential for the development of less than 50 to 60 stump sprout clumps of desirable species (e.g., oaks and basswood) per acre, interplantings may be compatible with coppice. However, where stump sprouts are expected to exceed 30 to 40 clumps per acre, I recommend using the RH80 success criteria in calculating stocking needs.

The development of guidelines for evaluating the potential of advance natural reproduction and stump sprouting¹ could

¹Ivan L. Sander, Paul S. Johnson, and Richard F. Watt. 1975. A guide for evaluating the adequacy of oak advance reproduction. Unpublished manuscript on file at the North Central Forest Experiment Station, Columbia, Missouri.

provide an objective basis for determining required numbers of supplemental interplanted trees. However, longer term interplanting studies will be needed to determine the potential contribution of interplantings to future stocking needs because measures of stocking (e.g., Roach and Gingrich 1968) are usually not practical until stands are 15 to 20 years old.

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	a	b
Lower slopes	0.0725	0.0965
Middle slopes	.0325	.0945
Upper slopes	.0400	.0820

SMI is then weighted by soil depth to produce a measure of site quality. For convenience, these weighted indices are re-scaled to a 0.1 (poorest site) to 1.0 (best site) value range, and termed "topographic site coefficients" (TSC). The final relation, where soil plus parent material depth is in inches (within a depth range of 10 to 50 inches), can be expressed:

$$TSC = (SMI) (\text{soil+parent material depth}) \\ 0.05332 + 0.04395.$$

APPENDIX I.--

DERIVATION OF TOPOGRAPHIC SITE COEFFICIENTS

A topographic site coefficient is a measure of site quality based on soil plus parent material depth to bedrock (to a maximum depth of 50 inches) weighted by an index of average growing season soil moisture associated with slope position and aspect (azimuth). Its derivation is based on the azimuth transformation (A_t):

$$A_t = \cos(\text{azimuth} - 45^\circ) + 2.$$

This transformation yields values from 1 (southwest facing slopes) to 3 (northeast facing slopes). Southeast and northwest slopes have values of 2, which is also the value assigned to level topography and all slopes less than 15 percent.

Base values for soil moisture indices were derived from measurements made by Stoeckeler and Curtis (1960) for a southern Wisconsin oak stand occupying north and south aspects. Soil moisture measurements on three slope positions (upper, middle, and lower thirds) within each aspect provided paired points for constructing three linear relations between soil moisture index (SMI) and transformed azimuth (A_t). For each slope position, the relation can be expressed by the following equation:

$$SMI = a + b(A_t),$$

for which the following values of a and b were derived:

APPENDIX II.--

EQUATIONS FOR PREDICTING HEIGHTS

FROM FIELD GROWING SEASONS AND SITE.

$$(1) \text{ HEIGHT}_{(RH60)} = -0.0716 + 1.0645(\text{fgs}) + \\ 0.3644(\text{TSC})(\text{fgs})$$

where: HEIGHT is in feet; observed values for height = (0.6 x measured value).

fgs = number of field growing seasons.

TSC = topographic site coefficient (see Appendix I).

$R^2 = 0.89$; $p = <0.01$, $n = 382$;
 $Sy \cdot x = 2.65$; regression coefficients are significantly different from 0 at the 0.01 level.

$$(2) \text{ HEIGHT}_{(RH80)} = -0.0954 + 1.4194(\text{fgs}) + \\ 0.4859(\text{TSC})(\text{fgs})$$

where: HEIGHT is in feet; observed values for height = (0.8 x measured value).

fgs = number of field growing seasons.

TSC = topographic site coefficient (see Appendix I).

$R^2 = 0.89$; $p = <0.01$; $n = 382$;
 $Sy \cdot x = 3.53$; regression coefficients are significantly different from 0 at the 0.01 level.

Topographic site coefficients at Albany ranged from 0.27 to 0.63, and at Coulee from 0.62 to 0.85.

APPENDIX III.--REGRESSION EQUATIONS FOR HEIGHT ATTAINMENT PROBABILITIES

ESTIMATED FROM AGE

Regression estimates in figures 2 and 3 are based on the logistic function and a model that restricts probability estimates (P) to a closed interval of 0 to 1 (Hamilton 1974). The model can be expressed as:

$$P = \{1 + \exp[-(B_0 + B_1X_1 + B_2X_2)]\}^{-1}$$

where X_1 = number of field growing seasons (fgs) and $X_2 = fgs/(age + 1)$. The observed value of the dependent variable (an individual tree) assumes a value of 1 (success) or 0 (failure). For each tree the observed probability of success at time of planting (0 field growing seasons) was 1 because heights of red oak stump sprouts (the standard on which interplanting success was based) were assumed to be zero.

Because the customary measure of goodness-of-fit for regression relations, the

error mean square, is not appropriate when the dependent variable is dichotomous, goodness-of-fit was based on:

- (1) "t" tests that determine whether each of the estimated parameters is significantly different from 0,
- (2) an analysis of variance using the F statistic to test the significance of the variation explained by regression, and
- (3) a chi-square analysis that evaluates differences between observed and predicted numbers of events within probability intervals of width 0.05. (The latter test was used primarily for comparing alternative models.)

Regression equations and goodness-of-fit statistics are given in table 3.

APPENDIX IV.--DERIVATION OF PLANTING FACTORS

The following relations, based on the binomial distribution, assume interplanted trees attain "success" status independently of one another with equal probabilities.

Table 3.--Regression equations for height attainment probabilities estimated from age

ALBANY PLOTS									
Species	Success criteria	Regression coefficients			Significance level ¹			Chi-squared	Observations
		B ₀	B ₁ (age)	B ₂ (1/(age+1))	"t"				
					B ₁	B ₂			
									(Number)
American basswood	RH80	-4.3523	(²)	8.1425	(²)	0.01	NS		460
	RH60	-2.5675	-0.0498	6.4988	NS	.01	NS		460
Northern red oak	RH80	-5.3678	.2706	.1188	0.05	.01	NS		475
	RH60	-3.5158	.1847	9.5497	.05	.01	NS		475
Red maple	RH80	-3.3563	.3151	6.6632	.01	.01	NS		452
	RH60	-2.0854	.2083	6.5739	.01	.01	NS		452
Sugar maple	RH80	-3.0634	.2936	5.9674	.01	.01	0.05		470
	RH60	- .2678	(²)	3.2682	(²)	.01	NS		470
White ash	RH80	.4568	- .1935	5.1524	.05	.01	NS		549
	RH60	.1981	(²)	6.6287	(²)	.01	NS		549
Yellow-poplar	RH80	- .0159	- .1184	4.4432	NS	.01	NS		480
	RH60	.6429	- .1565	3.8605	.05	.01	NS		480
COULEE PLOTS									
Northern red oak	RH80 ³								
	RH60	-0.1121	0.8661	0.1563	0.01	0.01	0.01		1,004
Sugar maple	RH80	- .1608	1.4951	.2166	.01	.01	NS		535
	RH60	-8.1246	.8432	.1108	.01	.01	.01		535
White ash	RH80	-8.7873	.5902	.1676	.01	.01	NS		493
	RH60	-7.6666	.6514	.1775	.01	.01	.01		493
Yellow-poplar	RH80	-13.2956	18.3823	1.2024	.01	.01	NS		1,008
	RH60	-7.8944	- .7435	11.7716	.01	.01	NS		1,008
¹ NS = nonsignificant									

¹NS = nonsignificant ($p \geq 0.05$); $p < 0.01$ for all regression F tests.

²Variable not included in equation.

³The observed probabilities were too small to permit calculation of regression.

Let:

S_n = the number of successful trees at the end of the eighth field growing season out of n trees originally interplanted;

p = the probability that a single tree will survive and reach a given relative height after eight field growing seasons (from table 1); and

q = the probability that a single tree will not survive and reach a given relative height after eight growing seasons ($q=1-p$).

The probability of having $S_n = k$ trees out of n initial trees at the end of the eighth growing season is given by the binomial distribution:

$$p(S_n = k) = \binom{n}{k} p^k \cdot q^{n-k}. \quad (1)$$

Note that $p(S_n \geq 1) = 1 - p(S_n = 0)$. (2)

If we wish to produce at least one successful tree at the end of the eighth field growing season with 80 percent probability, then substituting in (2):

$$0.80 = 1 - p(S_n = 0)$$

$$p(S_n = 0) = 0.20;$$

letting $k = 0$ in (1):

$$p(S_n = 0) = \binom{n}{0} p^0 q^{n-0}$$

which reduces to:

$$p(S_n = 0) = q^n$$

$$q^n = 0.20$$

$$n \cdot \log_{10} q = \log_{10}(0.20)$$

$$n = \frac{\log_{10}(0.20)}{\log_{10} q} = \text{planting factor}.$$

Johnson, Paul S.

1976. Eight-year performance of interplanted hardwoods in southern Wisconsin oak clearcuts. USDA For. Serv. Res. Pap. NC-126, 9 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Of six species interplanted in oak clearcuttings, sugar maple, red maple, and white ash were the most successful. Other species planted were northern red oak, yellow-poplar, and American basswood. Gives numbers of trees that should be planted for each species and initial size of planting stock.

OXFORD: 237.5(775). KEY WORDS: regeneration, planting, white ash, yellow-poplar, northern red oak.

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